# PATENT SPECIFICATION

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## (54) FLASH LIGHTING ARRANGEMENT

(71) We, MULTIBLITZ DR. ING. D.A. MANNESMANN GmbH. & Co. KG., a German Company of 505 Porz-Westhoven, Oberstrasse 89, Germany, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a flash lighting arrangement for generating short-wave radiation flashes of high intensity by using a flash tube ignitable by means of an ignition electrode and a storage capacitor discharging via the flash tube.

Arrangements of the type indicated are used in connection with the photoinitiation of drying or hardening processes, for instance, in varnishes or printing inks, where intensive short-wave radiation of very short duration is required and excessive heating from long-wave radiation is substantially avoided. Tests of this type have been carried out and have also led to positive results, but these positive results were not reproducible. Tests which at one time had positive results with specific flash tubes, storage capacitors and charging voltages and showed good drying and hardening effects, at other times could not be reproduced under apparently the same conditions.

The invention is based on an investigation of such flash lighting arrangements for the photoinitiation of drying or hardening processes with the purpose of determining the parameters critical for a positive result of the respective tests and of indicating principles for technical action which will lead to reproducible results.

According to the present invention there is provided a flash lighting arrangement for generating shortwave radiation flashes of high intensity comprising a flash tube ignitable by means of an ignition electrode and a storage capacitor adapted to discharge via the flash tube, characterised in that the resistance of the discharge circuit connecting the flash tube to the capacitor is sufficiently low that the peak current of the discharge is substantially determined only by the flash tube impedance. This condition can be checked in that then, for instance, a further halving of the resistance in the discharge circuit has no noticeable influence on the flash current.

It has been found that immediately after ignition in the initial stage of the flash discharge the resistance of the flash tube is extremely small which apparently is due to the fact that the gas in the flash tube has not yet been heated by the discharge. The flash tube resistance is initially of the order of magnitude of a milliohm and thus, is smaller by several orders of magnitude than the value of a few ohms which is the flash tube resistance during normal discharge. In this initial stage of the flash discharge, therefore, the ohmic resistance of the leads, even if small with respect to the indicated "normal" flash tube resistance and amounting, for instance, to 0.1 ohm, has a noticeable influence. A reduction in the lead resistances results in a considerable increase in the peak currents of the flash discharge. It has been found in this connection that a useful photochemical effect is obtained which is reproducible.

Preferably, the resistance of the discharge circuit connecting the flash tube to the capacitor is sufficiently low that the flash current follows an oscillation characteristic which preferably passes through zero.

With a sufficient reduction in the lead resistances an oscillation of the flash current occurred, said oscillation passing through the zero point. The reduction of lead resistance also caused a strong increase in the peak current during the first half cycle of the oscillation at small half width. This oscillation does not comprise a discharge and recharge of the storage capacitor, as would occur in a normal oscillatory circuit. Instead the capacitor is discharged substantially exponentially. Now, it has furthermore been found that these flash discharges of high

intensity and associated with oscillations show particularly good photochemical effects.

Moreover, it is particularly advantageous if there is provided a flash tube of UV-transmitting material including a discharge channel and which includes a dead space at each end of the discharge channel, the volume of each dead space being at least equal to the volume of the discharge channel.

It has been found that with such a flash tube under otherwise the same conditions, printing ink dried in less than a tenth of the time attainable with a flash tube without such dead spaces.

Moreover, it has been shown during tests, on the one hand, with the same flash frequency and different capacitances of the storage capacitor, and on the other hand, with the same capacitance and different flash frequencies that, though an increase in the capacitance leads to a proportional shortening of the drying time, an increase in the flash frequency has a substantially stronger effect reducing the drying time approximately exponentially. As the capacitance of a pulsating flash tube is given by the product of frequency f and energy

$$W = \frac{C}{2} U^2$$

(C is the capacitance of the flash tube and U the voltage applied thereto), and as the tube has a given power rating, it is advantageous to operate with a relatively small energy per flash, i.e. with a small capacitance for the storage capacitor, and a higher flash frequency. In a further modification of this invention provision is therefore made that the flash tube is operated stroboscopically at a frequency in the range half, to double the mains frequency, such as between 25 and 100 cycles per second the energy of each individual flash being dependent on the load rating of the tube.

Embodiments of the invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a circuit diagram of a flash lighting arrangement according to the present invention;

Figure 2 illustrates a flash tube which can be used in the flash lighting arrangement;

Figure 3 illustrates a measuring arrangement used in the investigations on which the invention is based;

Figures 4*a*—*e* illustrate flash current curves which were observed in a first type of tube with different resistances in the discharge circuit and with a storage capacitor capacitance of 5 $\mu$F with the measuring arrangement of Figure 3;

Figures 5*a*—*e* and Figures 6*a*—*e* show corresponding curves for a storage capacitor of 10 $\mu$F, and 25 $\mu$F respectively;

Figures 7*a*—*d* illustrate the flash current waveforms for another type of flash tube with different capacitances of the storage capacitor;

Figures 8*a*—*d* are corresponding waveforms for a flash tube of the same type as in Figure 7, but with lower gas pressure, and

Figure 9 is a graph showing the depedence of the photochemical effect on the flash frequency.

A transformer 10 (Fig. 1) to whose primary winding 12 the a.c. mains voltage is applied, has two secondary windings 14 and 16. A rectifier bridge 18 via which a storage capacitor 20 is charged, is connected to the secondary winding 14. The storage capacitor 20 is connected to flash tube 22, the ohmic resistance of the external discharge circuit (capacitor, leads without flash tube) being symbolized by the resistance R.

The flash tube 22 is ignited via an ignition electrode 24, which is connected in the customary manner to the secondary side of an ignition transformer 26. An ignition capacitor discharges through the primary winding of the ignition transformer 26 and supplies an ignition pulse to the ignition electrode 24, by which the flash tube 22 is ignited. The ignition capacitor 28 is charged by the d.c. voltage applied to the flash tube 22 via a voltage divider 30, 32. The discharge takes place periodically at twice the mains frequency, for instance, 100 cycles per second, and the flash tube 22 is ignited at the same frequency.

For this purpose, a capacitor 38 is charged from the secondary winding 16 of the tranformer 10 through a rectifier bridge 34 and a charging resistor 36. The capacitor voltage rises approximately according to the curve 40 (Fig. 1) and finally ignites a thyristor 42 which discharges the ignition capacitor 28 via the primary winding of the ignition transformer 26. At the same time, the capacitor 38 discharges through the thyristor. This takes place during each halfperiod of the a.c. mains voltage, so that during each halfperiod the storage capacitor 20 is charged approximately according to the curve 44, the flash tube 22 is ignited and the storage capacitor discharges via the same.

The flash tube 22 is shown in a longitudinal section in Fig. 2. It has a relatively narrow straight tubular discharge channel 46. This discharge channel has dead spaces 48, 50 one at each end thereof, the volume of each of the dead spaces being approximately equal to the volume of the discharge channel 46. Electrodes 52, 54 extend axially through the spaces 48, 50 and end adjacent the ends of the discharge channel so that there is no discharge in the spaces 48, 50. The cross-section of the discharge channel 46 is not completely filled

by the flash discharge. The electron flash tube consists of UV-transmitting quartz.

The critical data of the described preferred embodiment are as follows:

Capacitance of the storage capacitor 20: 20 $\mu$F (low ohmic metallic paper capacitor)

Charging voltage of the storage capacitor: 3200 volts

Lead resistance R<5 milliohms

Tube data:

Discharge length 450 mm, internal diameter of the discharge channel 4 mm, filling pressure 350 mm of mercury, filling gas: xenon.

Fig. 3 illustrates schematically a measuring arrangement by means of which the effects of the different parameters on the functioning and the photochemical effect of the generated flash discharge were investigated. Corresponding parts are referenced by the same reference numerals as in Fig. 1.

An ohmic measuring resistor $R_1$ is connected in the discharge circuit. The voltage across this measuring resistor was applied to the y-plates of a storage oscillograph 56. The resistor $R_1$ was varied in part of the tests.

Measurements

Three different types of flash tubes were tested:

Type A is a conventional flash tube of 4 mm internal diameter and a dead gas volume as small as possible.

Type B is a flash tube of 10 mm internal diameter and electrodes directly fused into the ends similarly to type A.

Type C is a flash tube similar to Fig. 2 with dead spaces at each end of the discharge channel which latter also has an internal diameter of 4 mm.

In one embodiment a straight flash tube of type A 400 mm in length and having an internal diameter of 4 mm and filled with inert gas was used at a gas pressure of 270 mm of mercury. The storage capacitor was a metallic paper capacitor. For different storage capacitors of 5 $\mu$F, 10 $\mu$F and 25 $\mu$F with different lead resistances R, and measuring resistors $R_1$, the discharge curves shown in Figs. 4*a* to *c* to 6*a* to *c* were obtained.

It can be seen that the amplitude of the flash current at first increases only slightly, for instance from 550 amps to 595 amps, while maintaining the normal exponential discharge course. At a specific small lead resistance, however, a damped oscillation passing through zero is formed, the amplitude of the oscillation rising very strongly, for instance to 3640 amps at 5 $\mu$F. It can be seen that such oscillations are superimposed on the exponential discharge curve initially only slightly but increasingly with decreasing lead resistance.

It can further be seen from Figs. 4 to 6 that at 5 $\mu$F the decaying oscillation signal is mainly negative, whilst at 25 $\mu$F it is mainly positive. For a storage capacitance of 10 $\mu$F an oscillation characteristic is obtained which is substantially symmetrical about the zero line. This oscillation of Fig. 5 leads to a maximum current peak of 4730 amps if other conditions remain the same.

The peak current is substantially proportional to the voltage to which the storage capacitor is charged. Accordingly, the photochemical effect of the flash discharge at which ultraviolet radiation is apparently predominantly produced charges.

Therefore, the conclusions of the investigation of flash tubes of the type A are summarised as follows:

a) For a given flash tube the lead resistance is reduced until an oscillation, passing through zero, is produced in the flash tube.

b) In this condition it is possible for the storage capacitance to be varied until the oscillations take place symmetrically relative to the zero line.

This condition is reproducibly associated with high peak currents in the initial stage of the discharge, which shows results in a good photochemical effect provided the current exceeds a certain value. In the described investigation a peak current—measured with the assumption of a strictly ohmic resistance $R_1$—of about 2000 amps was found to be necessary in order to obtain useful results.

With a flash tube of type B similar results to those with the flash tubes of type A were obtained. However, the optimum of the oscillation effect was obtained at greater capacities of the storage capacitor, approx. 25—30 $\mu$F. However, the photochemical effect was not as good as that obtained with flash tubes of the type A under the same conditions.

With flash tubes of the type C no marked optimum of the oscillation effect in dependence on the capacitance of the storage capacitor 20 was obtained. This can be seen from the curves in Figs. 7*a*—*d* and Figs. 8*a*—*d* taken with such flash tubes. The capacitance, and therewith the energy stored in the storage capacitor 20 only influences the number of oscillations which occur until the capacitor is discharged.

As is recognizable from a comparison of Figs. 7 and 8, with tubes of the type C—in contrast to the types A and B—within broad limits practically no dependence of the oscillation characteristic on the filling pressure of the tube is obtained. Fig. 7 was recorded for a flash tube with a filling pressure of 350 mm of mercury, Fig. 8 for a flash tube with a filling pressure of 250 mm of mercury. With flash tubes of the type A or B oscillation effects of the described type are only obtained

at relatively low filling pressures of <280 mm of mercury.

The photochemical effect of the radiation flashes so generated was investigated by means of printing ink samples, wherein a measure of the effectiveness of the radiation flashes was the number of flashes necessary for sufficient drying of the printing inks (no smearing). Checks were made in that a reference part of each print sample was covered by an aluminium sheet. The following results were obtained:

For all flash tubes the best drying effects occurred only when the flash tube was operated in a condition in which the described oscillations were distinctly observable, type A being somewhat better than type B. With flash tubes of the type C, however, drying effects better by a factor of about 10 than with the other tubes were obtained.

With flash tubes of the type C an approximately linear variation of the capacitance of the storage capacitor with the flash energy (Wsec) and the drying effect was observed.

Moreover, the dependence of the drying effect, namely of the number of flashes required for drying at a given energy of each individual flash was measured. In this connection the decreasing logarithmic dependence of Fig. 9 was obtained. According thereto, it is favourable to operate at higher frequencies in order to attain drying times as short as possible.

Summary

Thus, it has been found to be favourable to use a flash tube of the type C. The lead resistance should be maintained as small as possible so that it practically has no influence on the discharge. In this manner the flash current is in an oscillatory state causing high initial current peaks. Such initial current peaks have a good photochemical effect. For a given thermal loading rating of the flash tube a relatively small capacitance of the storage capacitor (flash energy per flash) should be selected, while providing a higher flash frequency. The described preferred embodiment of Figs. 1 and 2 is typical of such a system.

The described phenomena could possibly be interpreted in the following manner:

The emission of short-wave UV is essential to the photochemical effect (varnish drying, drying of printing inks). This also results from theoretical considerations and is known per se. Such ultraviolet radiation occurs primarily in a flash tube with low gas pressure. If during the course of the flash discharge the gas pressure increases, the emitted spectrum moves towards the visible and long-wave range. The provision of dead spaces in the gas chamber of the flash tube according to type C counteracts such a pressure rise so that a higher yield of ultraviolet radiation is obtained.

For a sufficiently small lead resistance in which the peak current of the discharge is substantially only determined by the tube itself, it appears that plasma oscillations occur in the tube with high currents and probably high current densities which also favour the emission of optically effective radiation.

It has been found that the described oscillations are not oscillations of an oscillatory circuit comprising the tube and storage capacitor, as their frequency is not changed in an otherwise to be expected manner either by a change in the capacitance of the storage capacitor or by an additional inductance in the discharge circuit. Apparently the oscillation takes place in the tube itself.

WHAT WE CLAIM IS:—

1. A flash lighting arrangement for generating shortwave radiation flashes of high intensity comprising a flash tube ignitable by means of an ignition electrode and a storage capacitor adapted to discharge via the flash tube, characterised in that the resistance of the discharge circuit connecting the flash tube to the capacitor is sufficiently low that the peak current of the discharge is substantially determined only by the flash tube impedance.

2. A flash lighting arrangement as claimed in claim 1, wherein the resistance of the discharge circuit is sufficiently small that the flash current follows an oscillation characteristic which preferably passes through zero.

3. A flash lighting arrangement as claimed in claim 2, wherein said flash tube of UV-transmitting material comprises a discharge channel of UV transmitting material, and a dead space disposed at each end of the discharge channel, the volume of each dead space being at least equal to the volume of the discharge channel.

4. A flash lighting arrangement as claimed in claim 3 wherein said discharge channel is tubular and is made of quartz of an internal diameter less than 5 mm, which channel is not filled completely by the discharge.

5. A flash lighting arrangement as claimed in any one of claims 1 to 4, wherein the flash tube is operable at a frequency in the range half to double the mains frequency, such as

between 25 and 100 cycles per second, the energy of each individual flash being determined by the rating of the tube.

6. A flash lighting arrangement as herein described with reference to and as shown in the accompanying drawings.

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1346521 COMPLETE SPECIFICATION

7 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

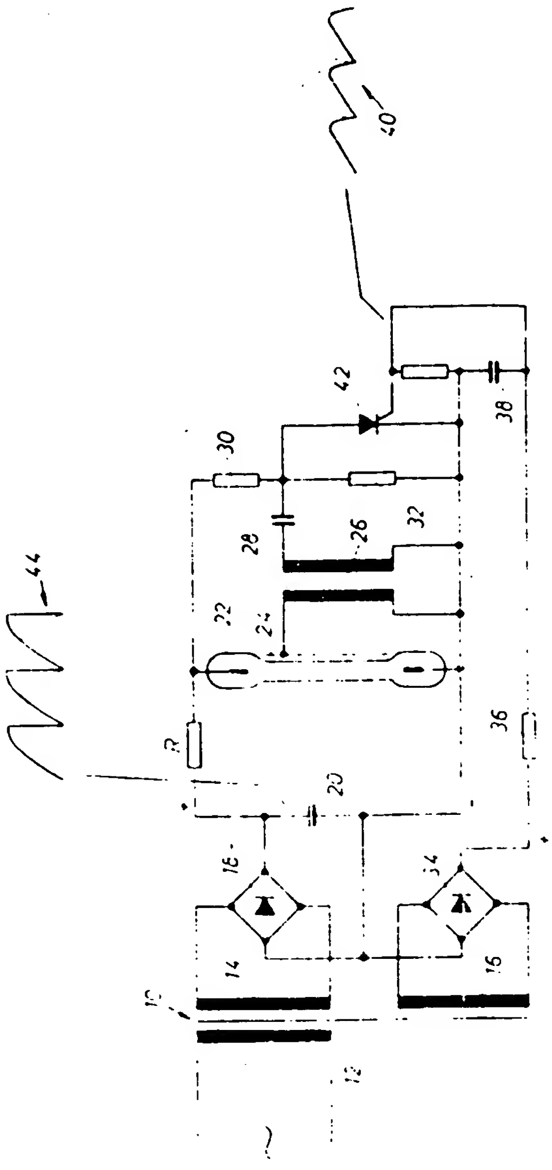

Fig. 1

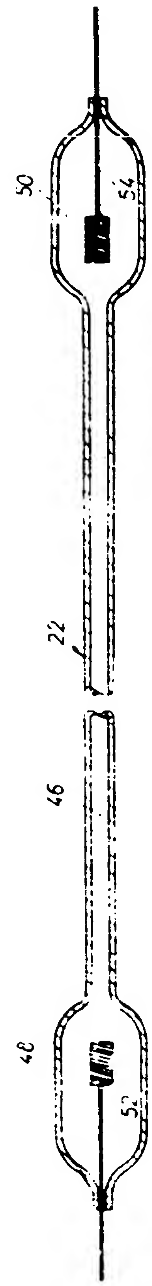

Fig. 2

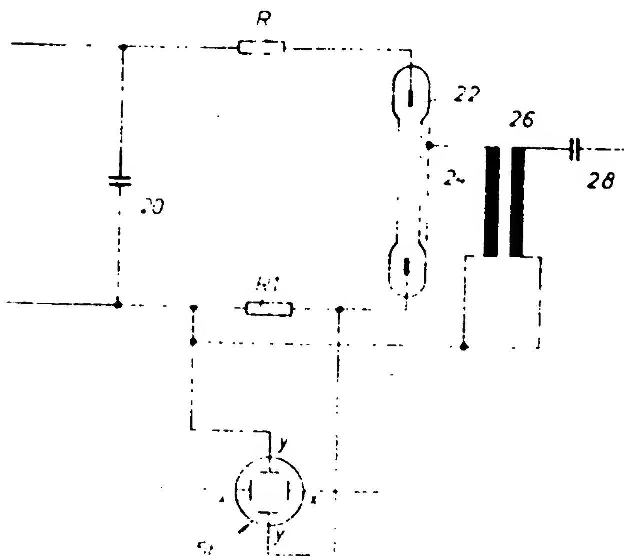


Fig 3

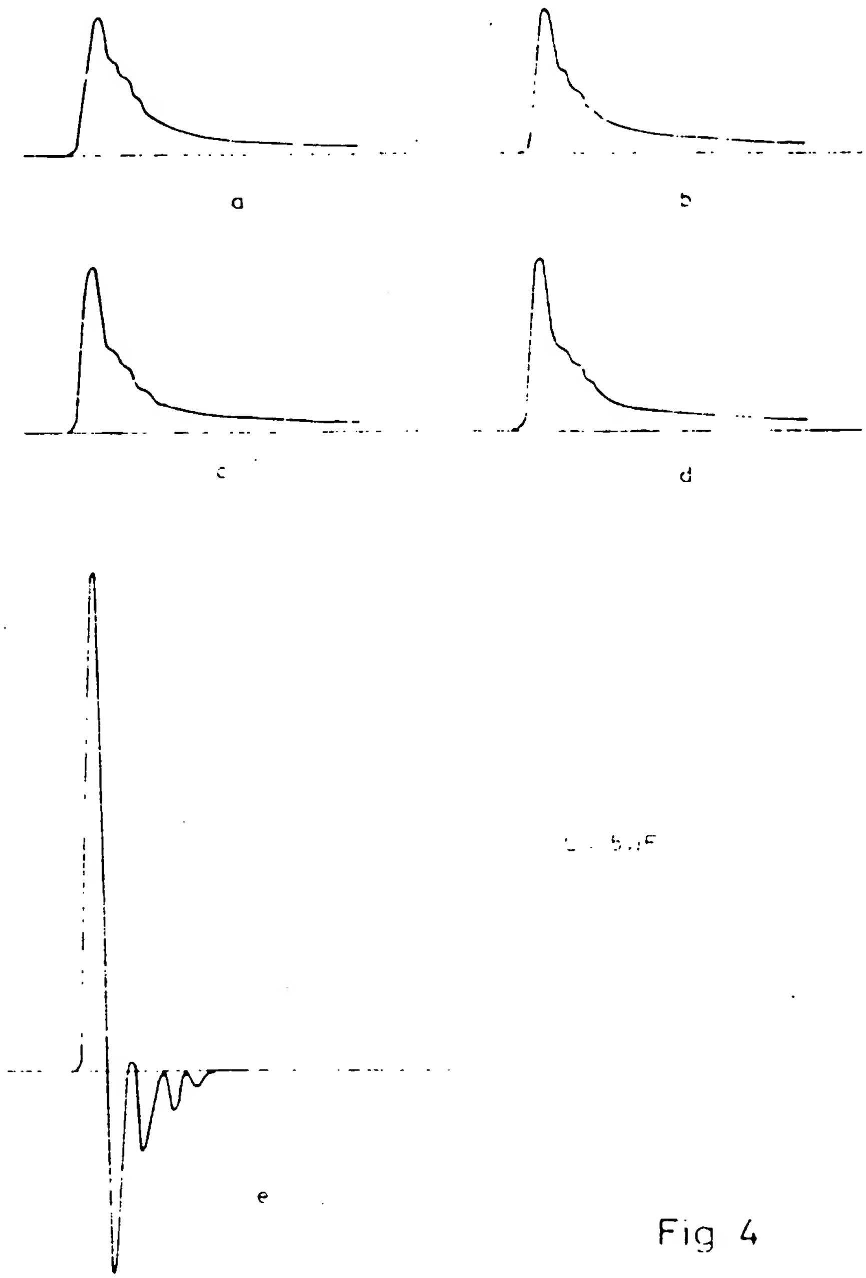


Fig 4

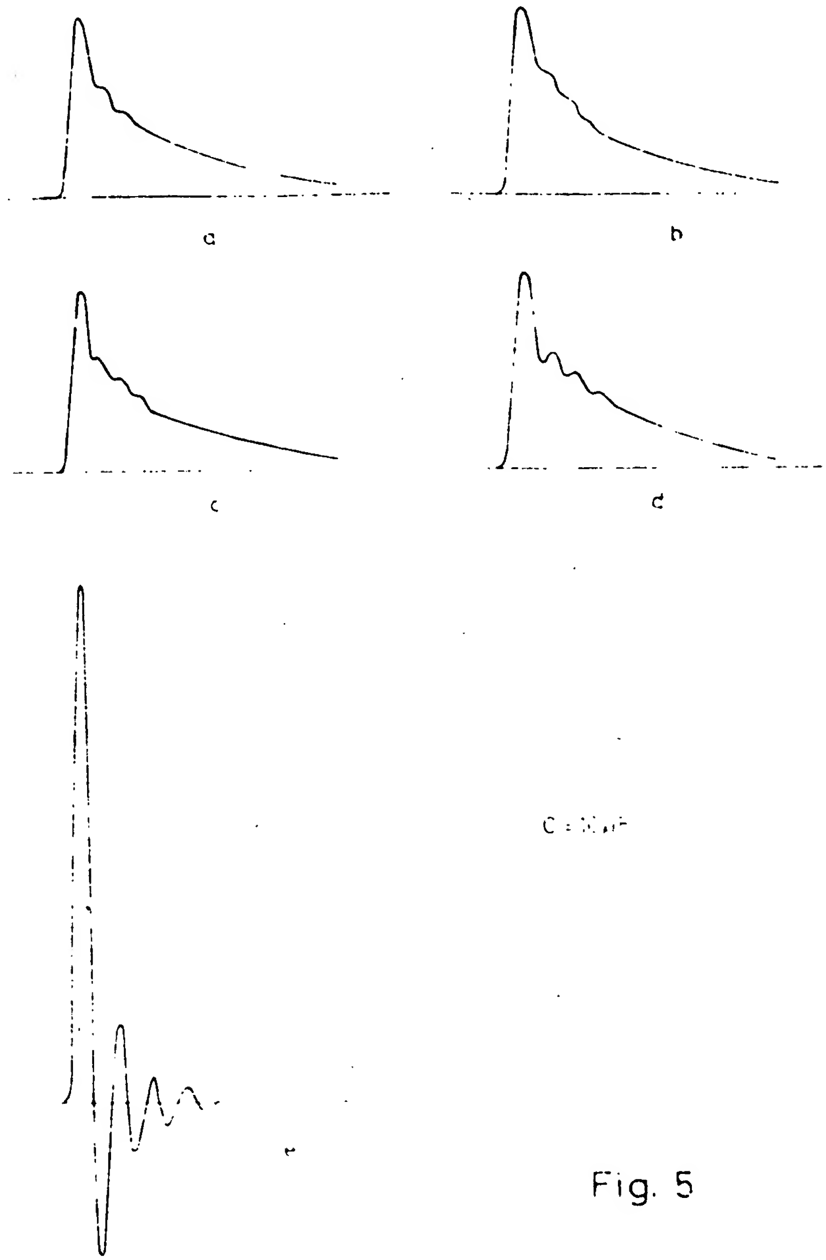


Fig. 5

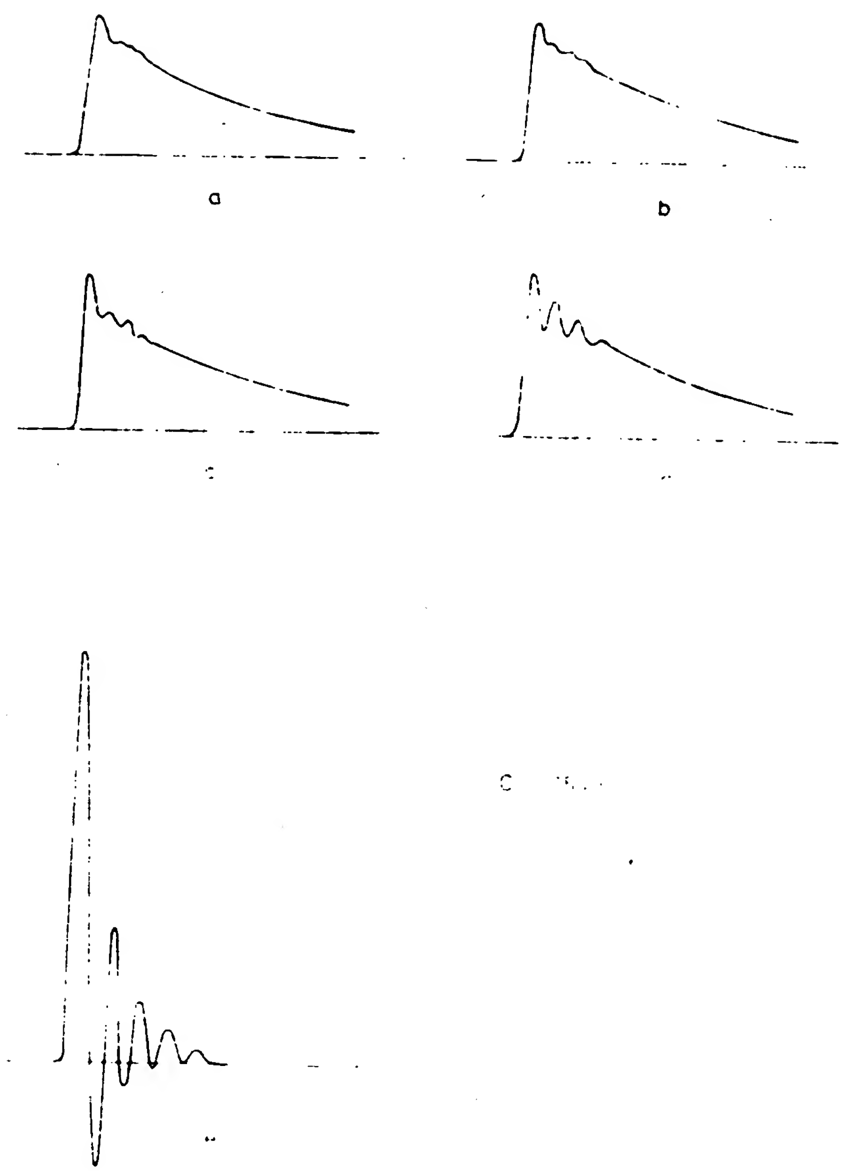


Fig. 6

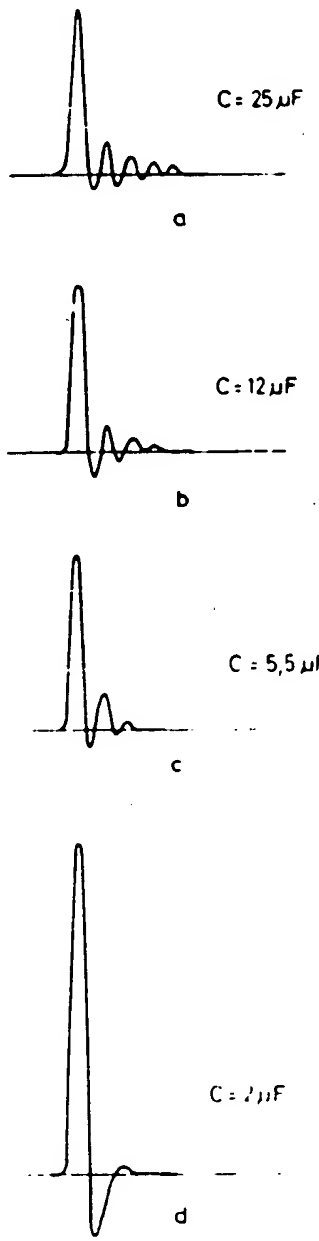


Fig. 7

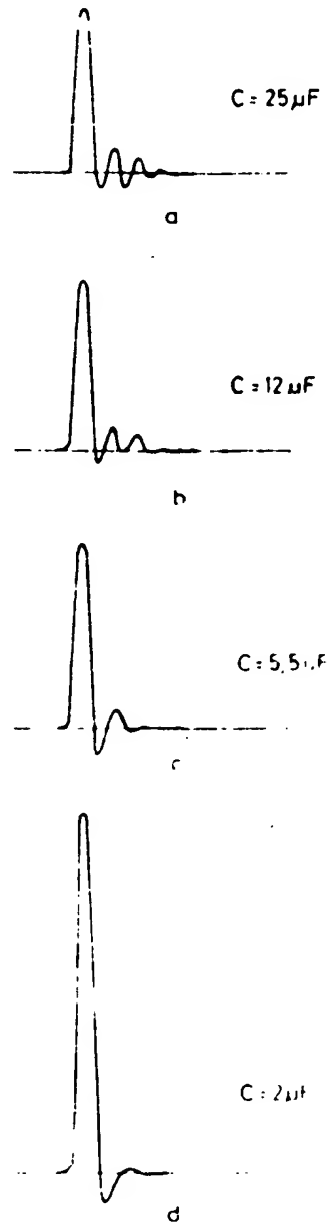


Fig. 8

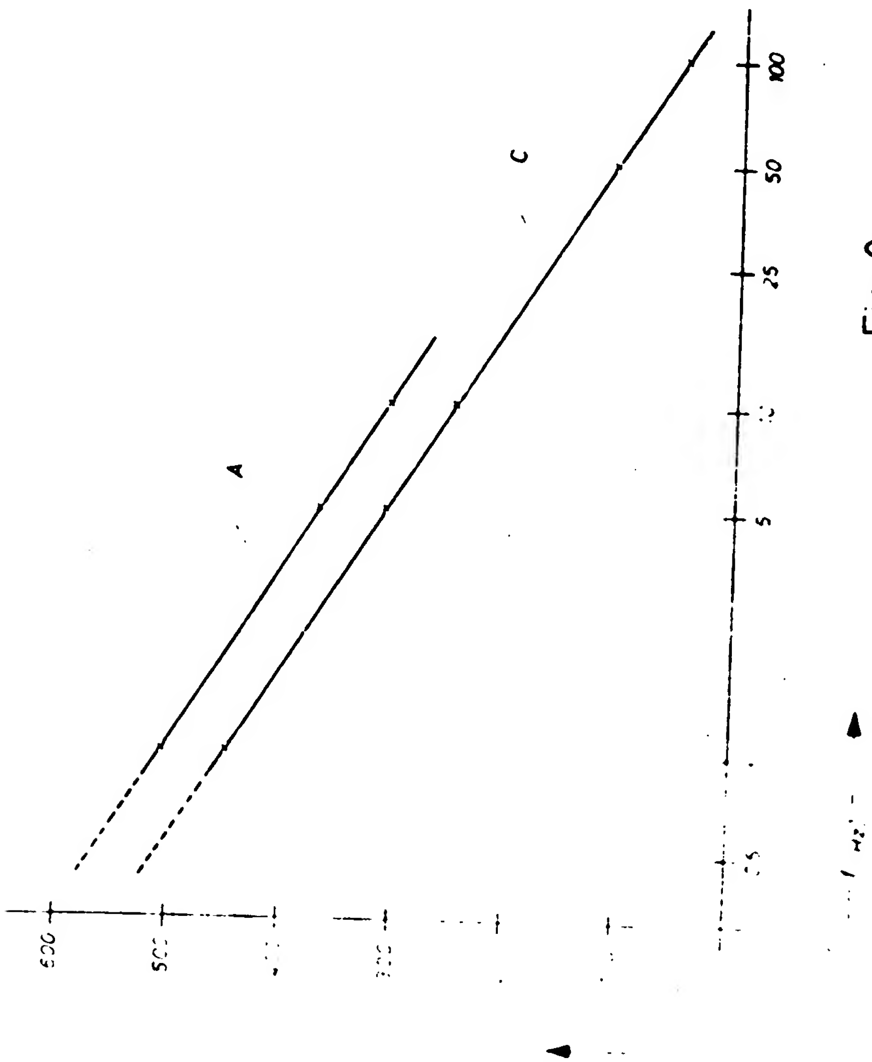


Fig. 9